Optical Simulations for MicroBooNE

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This Talk

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Intro / LarSoft / Simulation Chains

2 – Physics Processes

Physics Lists / Optical Processes / Optical Properties / Photon Stepping

3 – Hardware Description

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4 – New Preliminary Results

Point Source Test / Redundancy / Wire Blocking

5 – Fast simulation

Voxelization / Library Building and Sampling

6 – To be Implemented / Next steps

Timing / Digitization / Geometry / Detailed Studies

1 - Introduction

Status of Optical Simulations

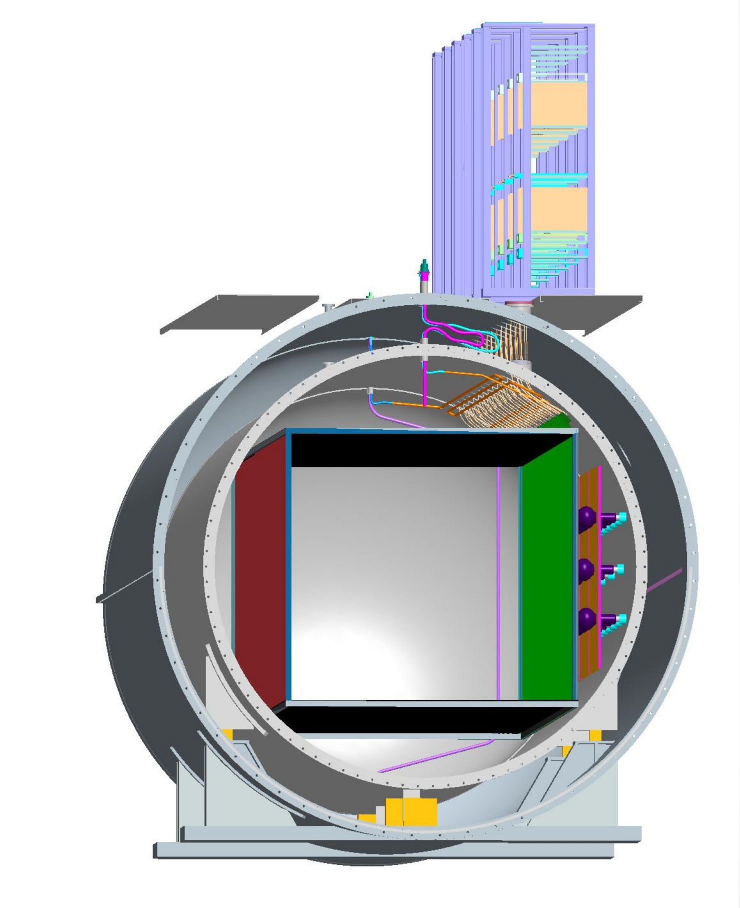
- Development of optical simulations for liquid argon experiments (and hence MicroBooNE) in LArSoft has been underway since last summer.
- Essential framework for full optical sim is in place and generating preliminary results
- Some improvements are still required before we can produce convincing predictions

I hope to show with this talk:

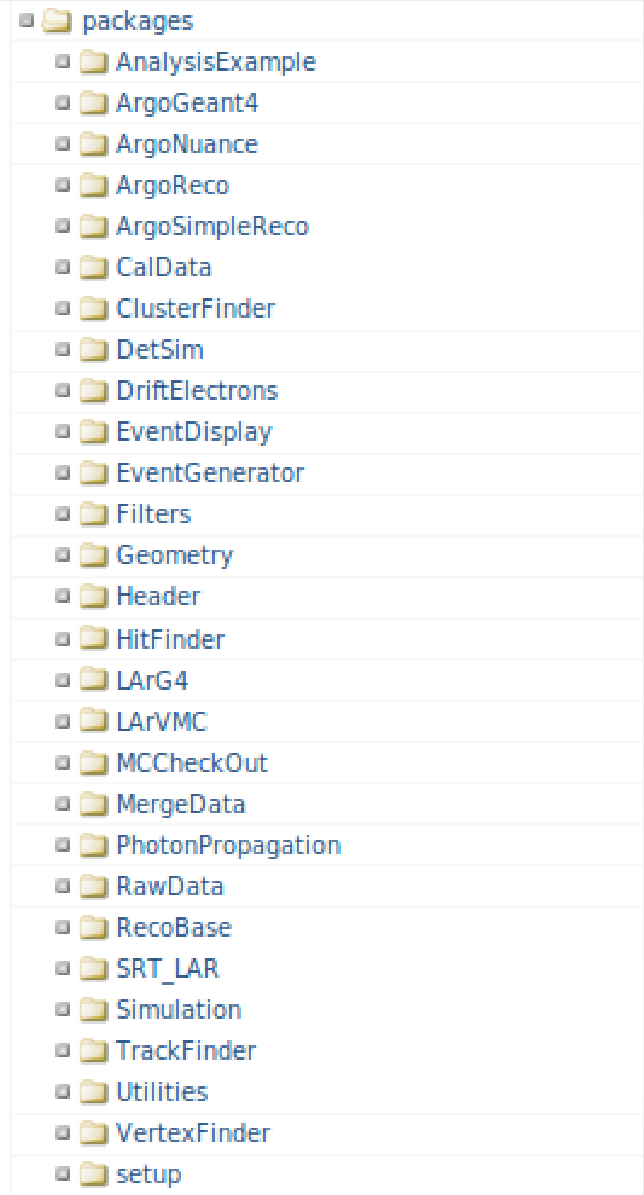
1) In a few weeks / months we will be in a position to run **detailed, accurate monte carlo simulations** of the MicroBooNE optical systems

2) A fast simulation will be in place and form a part of the **standard MicroBooNE simulation chain** by December

3) Our preliminary investigations support our conclusions from other calculations, that the optical systems are **suitably designed with sufficient redundancy** to perform triggering and aid in reconstruction of scintillation down to 5MeV



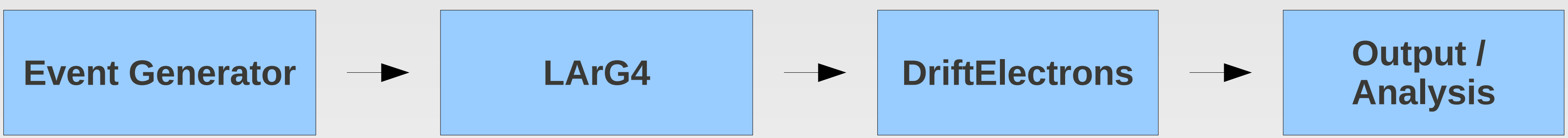
LArSoft



- All simulation tasks for MicroBooNE will be performed within the ***LArSoft*** framework.
- LArSoft is a simulation framework for liquid argon TPC's and is also the standard simulation package for ***Argoneut*** and ***LBNE***.
- LArSoft is built upon the ***FMWK*** framework and interfaces with other simulation packages – ***GENIE***, ***GEANT4***, ***CRY***, etc.
- ***MicroBooNE*** is the first LArSoft experiment to attempt detailed optical simulations within the LArSoft framework.
- As such, code development and validation has been a very sizeable task.

LArSoft Simulation Chain

- Simulation jobs in LArSoft are broken down into discrete steps.
- A typical simulation chain is shown below



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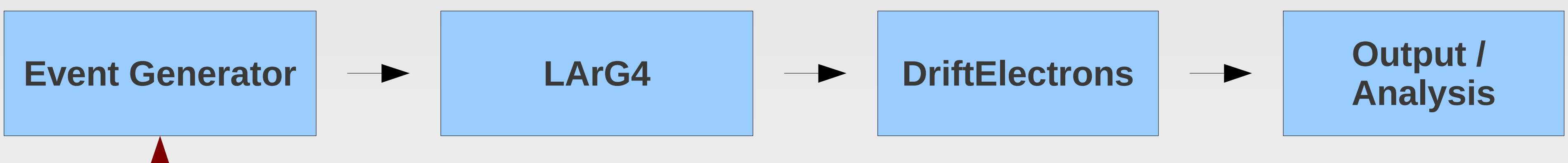

GENIE – Generate beam neutrino interactions

CRY – Generate cosmic ray interactions

SingleParticle – Particle gun for detector studies, etc

LightSource – New event generator developped for optical studies and library building, more later

LArSoft Simulation Chain

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- A typical simulation chain is shown below

Event Generator → **LArG4** → **DriftElectrons** → **Output / Analysis**

Interface with GEANT4

Simulate the interaction of particle with matter. Here we include the production and stepping of optical photons within the detector. Much more about this later.

LArSoft Simulation Chain

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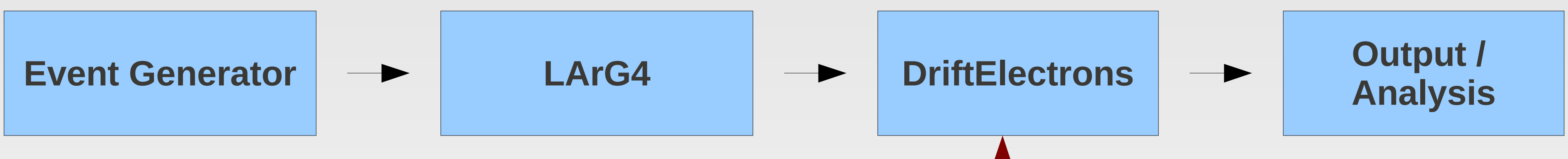

TPC Simulation

Simulate the drift of liberated ionization electrons in the TPC field and generate wire hits.

This module does not affect optical studies, but a parallel module is being developped for photon propagation.

LArSoft Simulation Chain

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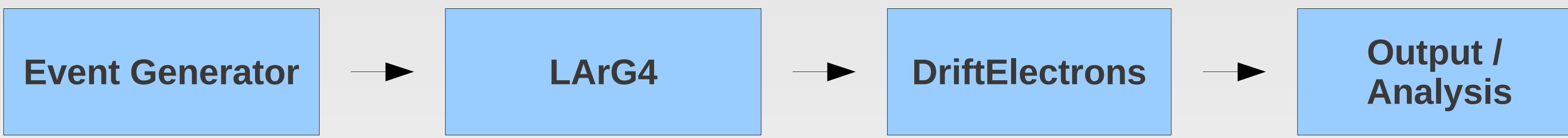


What is the task at hand?

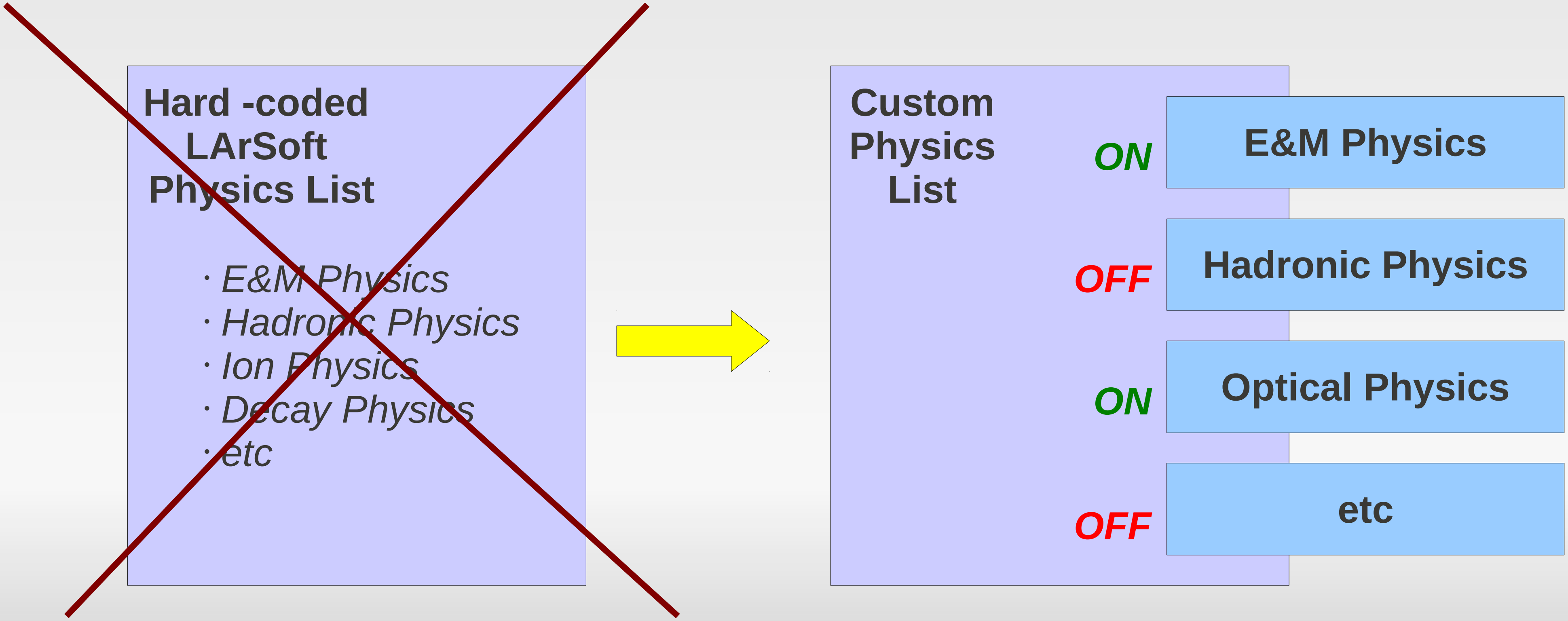
This step will depend entirely on what information we want to extract from the event.

New data formats and purpose built analysis modules have been built for optical studies, but may not all be described in detail in this talk

2 – Physics Processes

Physics Lists in LArSoft

- Not all experiments have optical systems – and not all simulation runs have the same optical physics requirements. We want tight control over which physics processes are loaded into the GEANT4 simulation for each run.
- Hence the first step to building the optical physics sim was a rewrite of the LArSoft physics list handling system



Optical Processes in LArG4

Optical physics processes are loaded via the ”OpticalPhysics” GEANT4 physics constructor, which was customized to fit our needs in LArSoft.

(for full details, please refer to the TDR)

Optical Physics

- **Scintillation production** *(fast and slow)*
- **Cerenkov production**
- **Rayleigh Scattering**
- **Reflections** *(specular and diffuse)*
- **Absorption at surfaces**
- **Wavelength shifting**
- **Absorption in argon bulk** *(currently none)*

Optical Properties of Materials

- Optical properties of materials are loaded during the detector construction step using the MaterialPropertyLoader class.
- The requirement of loading wavelength dependent parameters required us to step outside the default gdml parser and implement this new class.
- Several implementations are possible (xml reading, hard coded, etc)

Per Material Type

Scintillation

Fast component spectrum
Slow component spectrum
Scintillation yield
Fast time const
Slow time const
Proportion fast / slow
Quenching per particle

Cerenkov

- none -

Absorption

Absorption Length

Rayleigh Scattering

Scattering Length

WLS

Absorption spectrum
Emission spectrum
Time Constant
Yield out / in

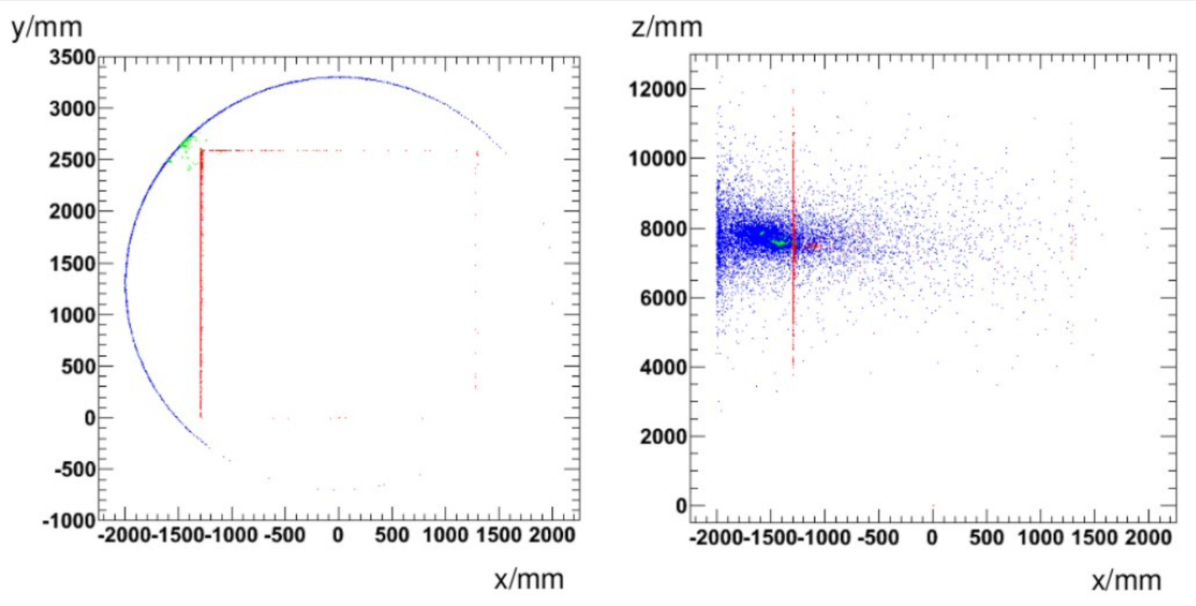
Per Boundary Type

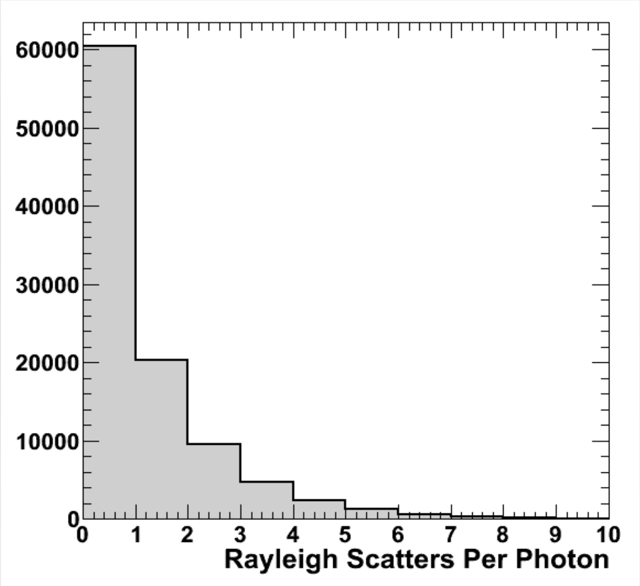
Reflections

Total Reflectivity
Fraction specular / diffuse

Wavelength dependent
Non wavelength dependent

A Sample Neutrino Event in LArG4

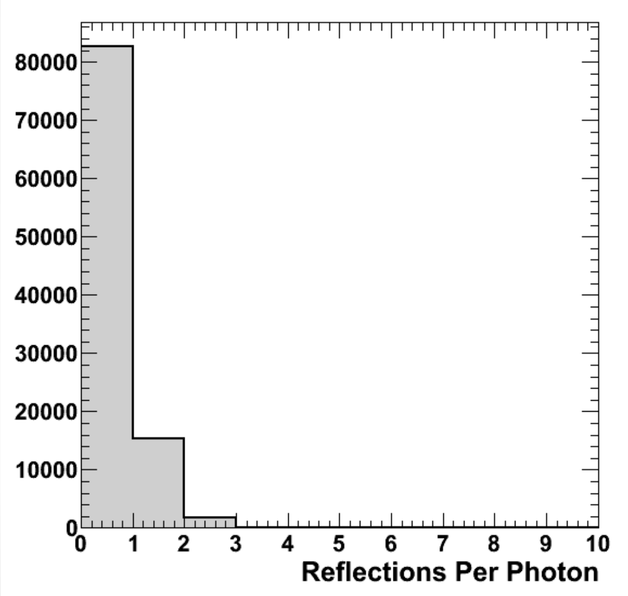




Green - Photon production

Blue - Photon absorption at surface of known reflectivity

Red - Photon absorption at surface with no reflectivity data

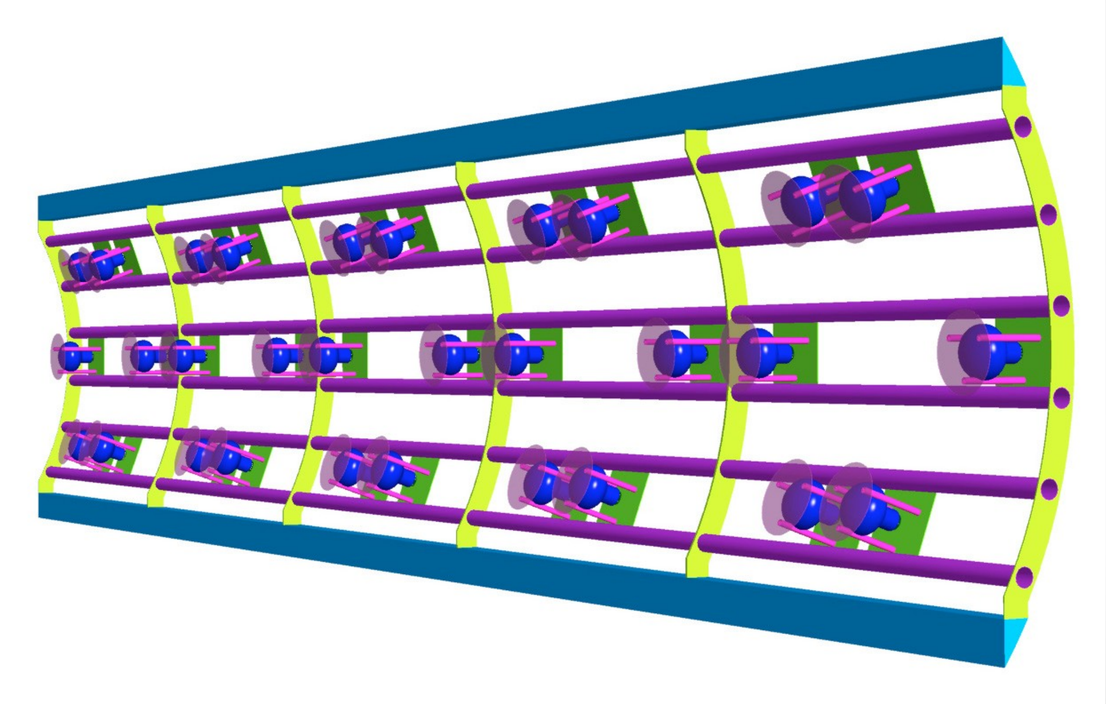


- 95161 photons were generated of which 58996 were eventually absorbed at a steel surface and 20932 were absorbed into a ”black area”
- Each photon underwent a mean of 0.76 Rayleigh scatters and 0.19 reflections

3 – Hardware Description

PMT Placement and Geometry

- The geometry files used for LArSoft experiments are written in the **GDML** language and built using a set of geometry generation scripts
- **PMT geometry** definition and placement scripts have been added
- **microboone.gdml** has been rebuilt with coordinates from one possible 30 PMT design
- PMTs are placed by supplying the **x,y,z coordinates of the centre of the PMT lens ellipsoid** and the **direction of the lens normal**
- During geometry parsing, PMT components are used to build a **parallel world volume** and appropriate **sensitive volumes** with **PMT ID's** are assigned
- Other **PMT geometries** (30Rack-A, 30Rack-B, 40Rack) can be built and compared simply by supplying a new set of PMT coordinates and running a script



PMTs in LArSoft

2) AcrylicPlate

Shape:
Cylinder

Material:
Acrylic

4) PMTUnderside

Shape:
Ellipsoid

Material:
Solid Glass

5) PMTStalk

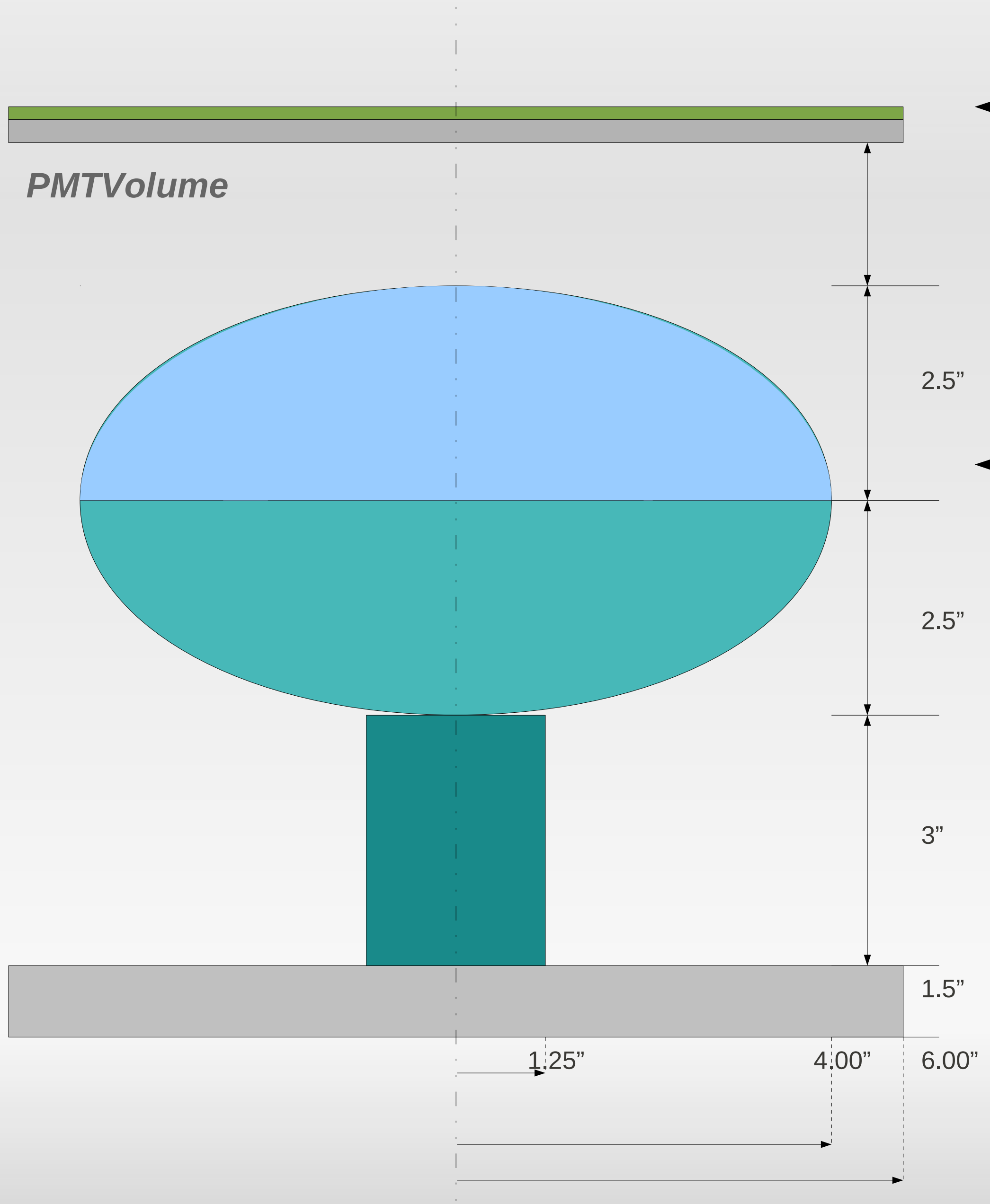
Shape:
Cylinder

Material:
Solid Glass

6) PMTSteelBase

Shape:
Cylinder

Material:
Stainless Steel



1) TPBCoating

Shape:
Cylinder

Material:
TPB

Physics:
OpWLS Process in OpticalPhysics constructor

3) PMTLens

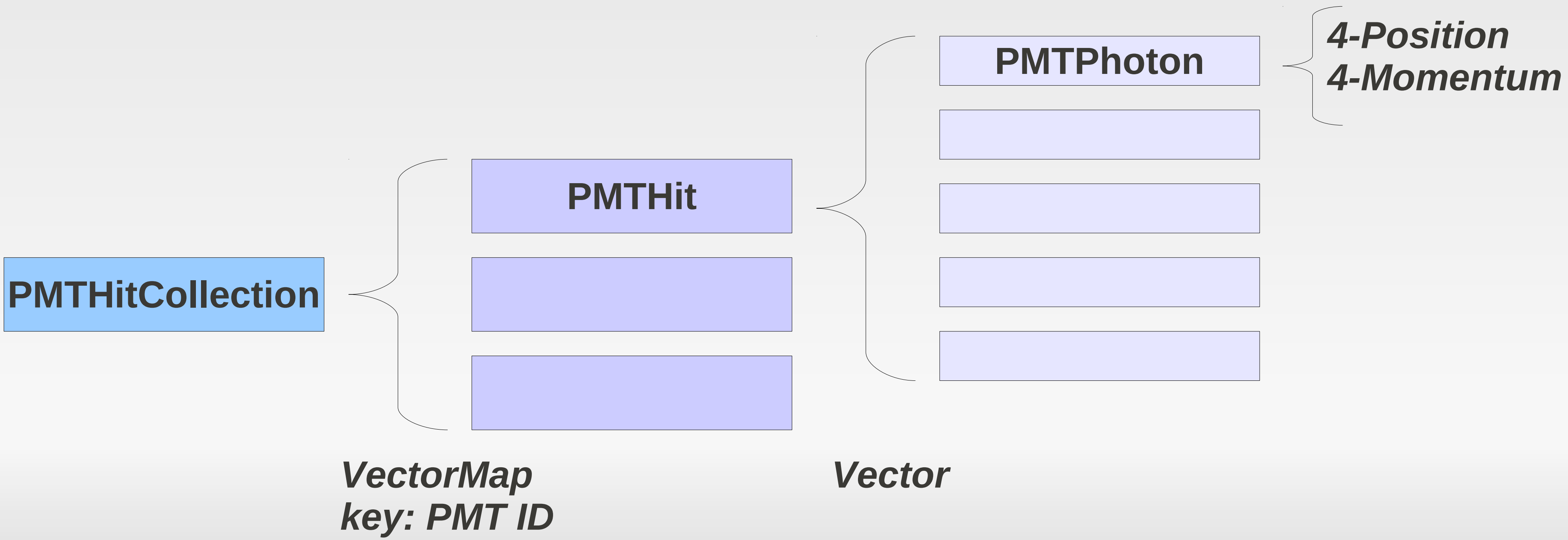
Shape:
Ellipsoid

Material:
LAr *

Physics:
PMTSensitiveDetector associated in DetectorConstruction

PMTHit Data Structures

- The optical information to be passed along the simulation chain from LArG4 is contained within a PMT hit collection
- The PMTHitCollection is a set of PMTHits, one for each PMT that saw one or more photon
- Each hit is a list of 4-positions and 4 momenta of photons which stepped across the lens of the PMT



The Light Source Event Generator

- Event generator which simulates an extended, isotropic light source at some position in the detector
- Two modes of operation:

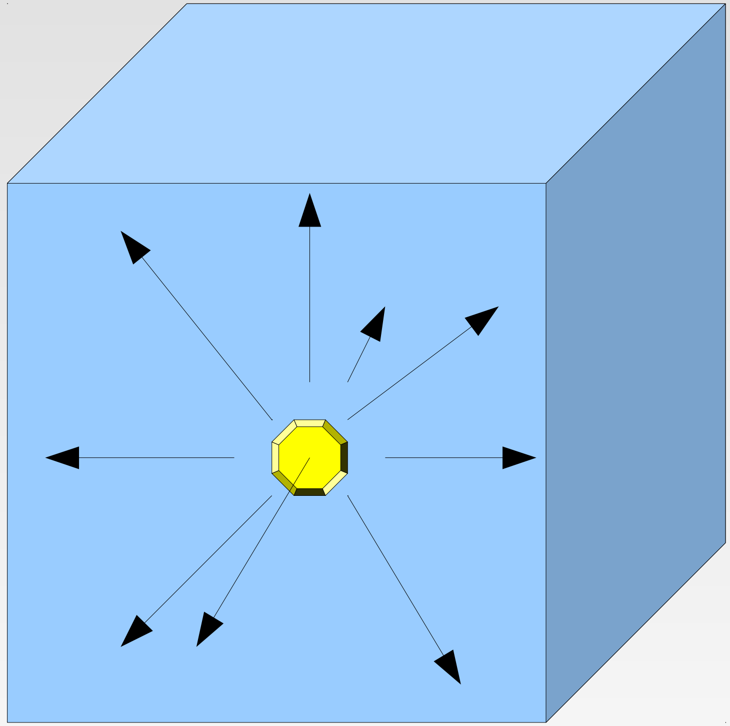
  - Scan Mode

  Voxelize the detector into cuboidal regions, and step through the volume deposittting N photons uniformly across one voxel per event.

  - File Mode

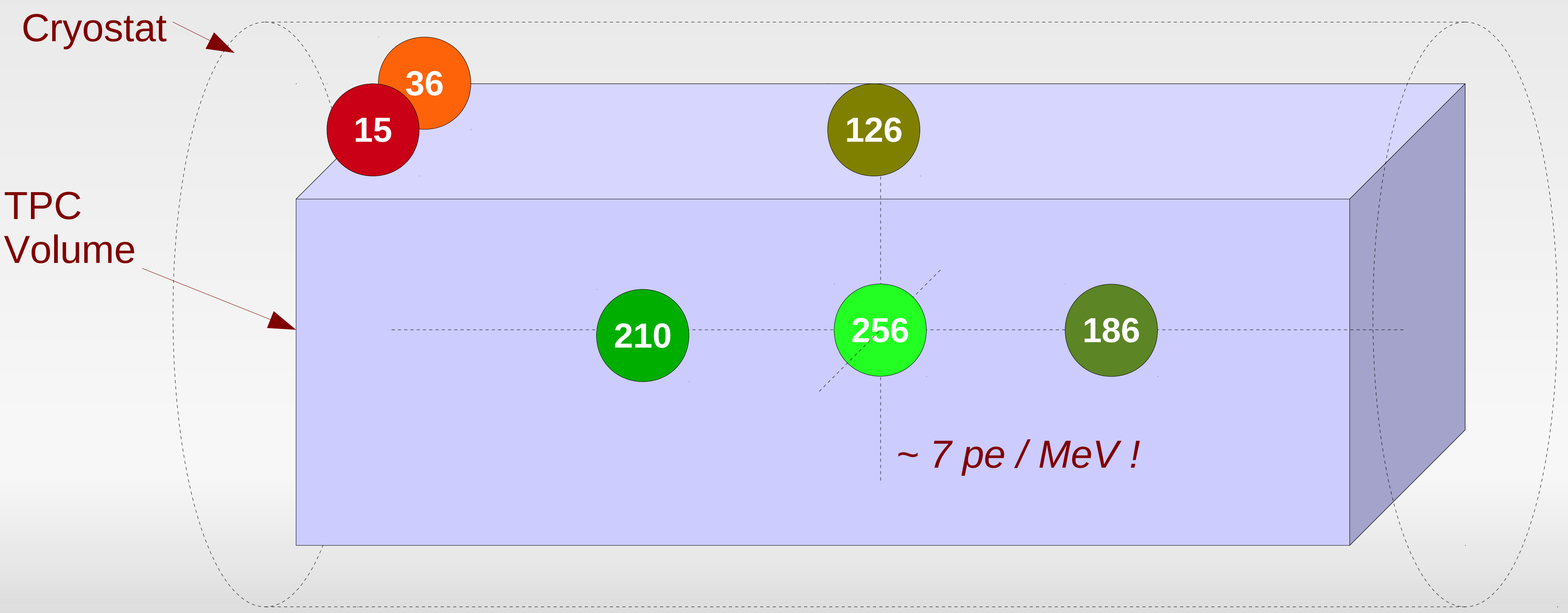
  Specify the size, intensity, shape and position of one light source for each event in a text file which is specified in the config file for the module.

- Optionally, a data structure can be stored in the event with details of the light source configuration



Preliminary Sensitivity Studies

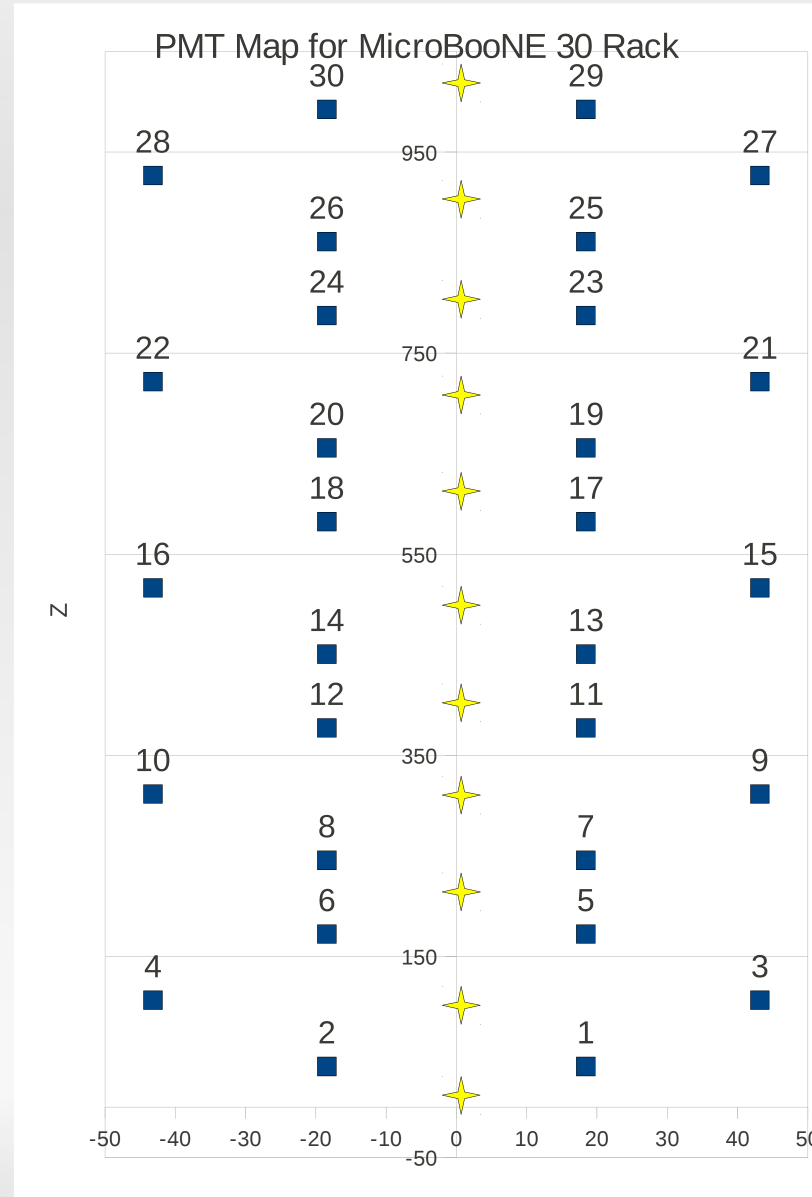
- Place light sources which produce 10,000 photons per event at different points in the detector geometry. This is over a factor of 10 smaller than a scintillating 5MeV proton.
- Ask how many photons make it to a PMT lens – all reflections and scatters enabled
- Note that in this preliminary study, PMT lenses are naked - no wavelength shifting plates. Hence we still need to factor in WLS related efficiencies. We estimate a factor of 0.03 (see TDR)



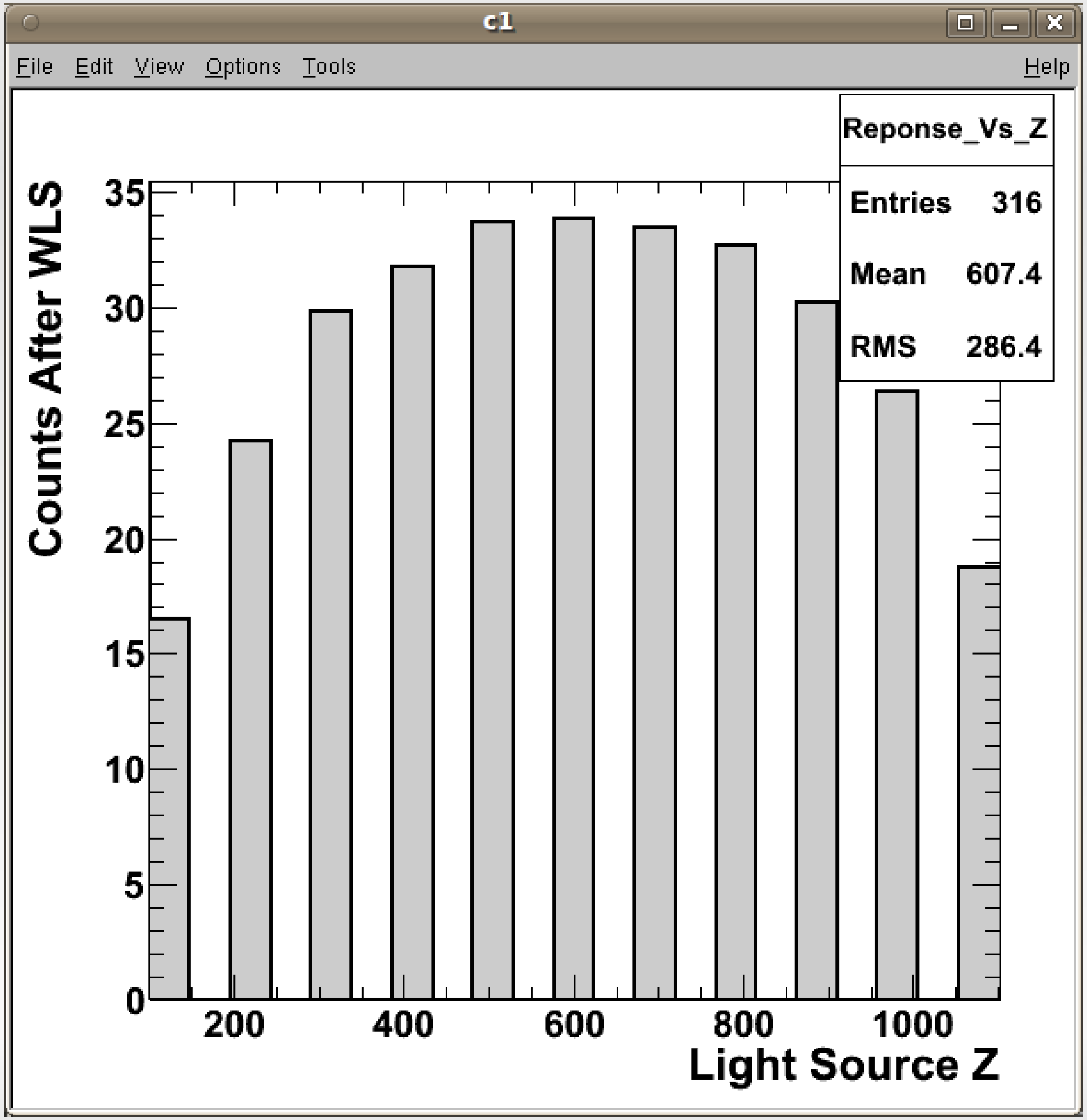
4 – New Preliminary Results

Preliminary – Point Source Test

- Place point light sources at various points in the detector
- Run full simulation with photons corresponding to **5MeV scintillation** (120,000 photons)
- Count photons reaching PMT lens
- Note – PMTs here are naked with no wavelength cut, need to include WLS efficiency. In our TDR, we estimate this to be 0.03.
- Until we have computing power to do more, we only consider on-axis points



Preliminary – Point Source Test

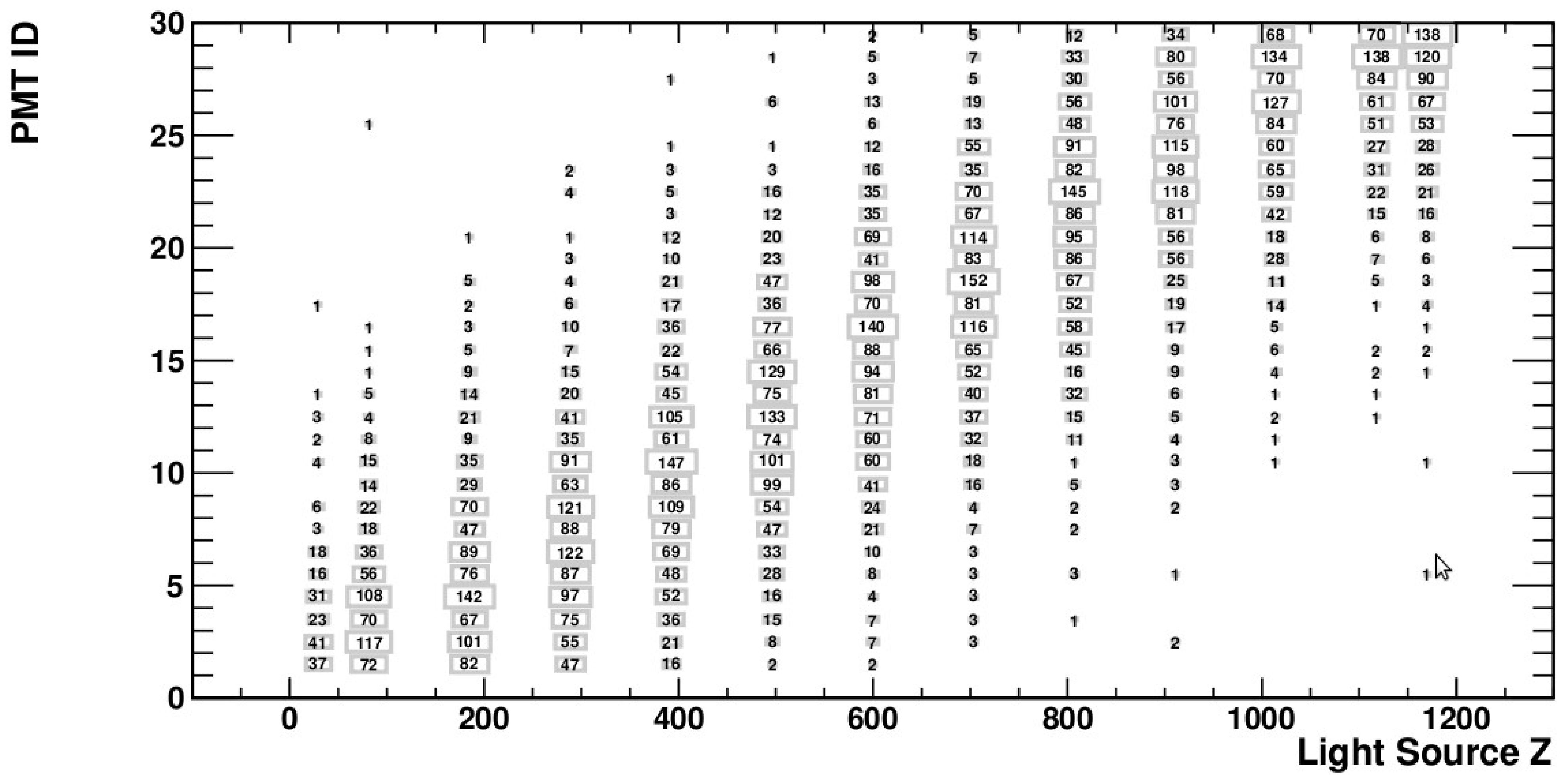


> 15 photoelectrons for each on-axis point in the fiducial volume!

Suggests we have good efficiency for even 5MeV of scintillation

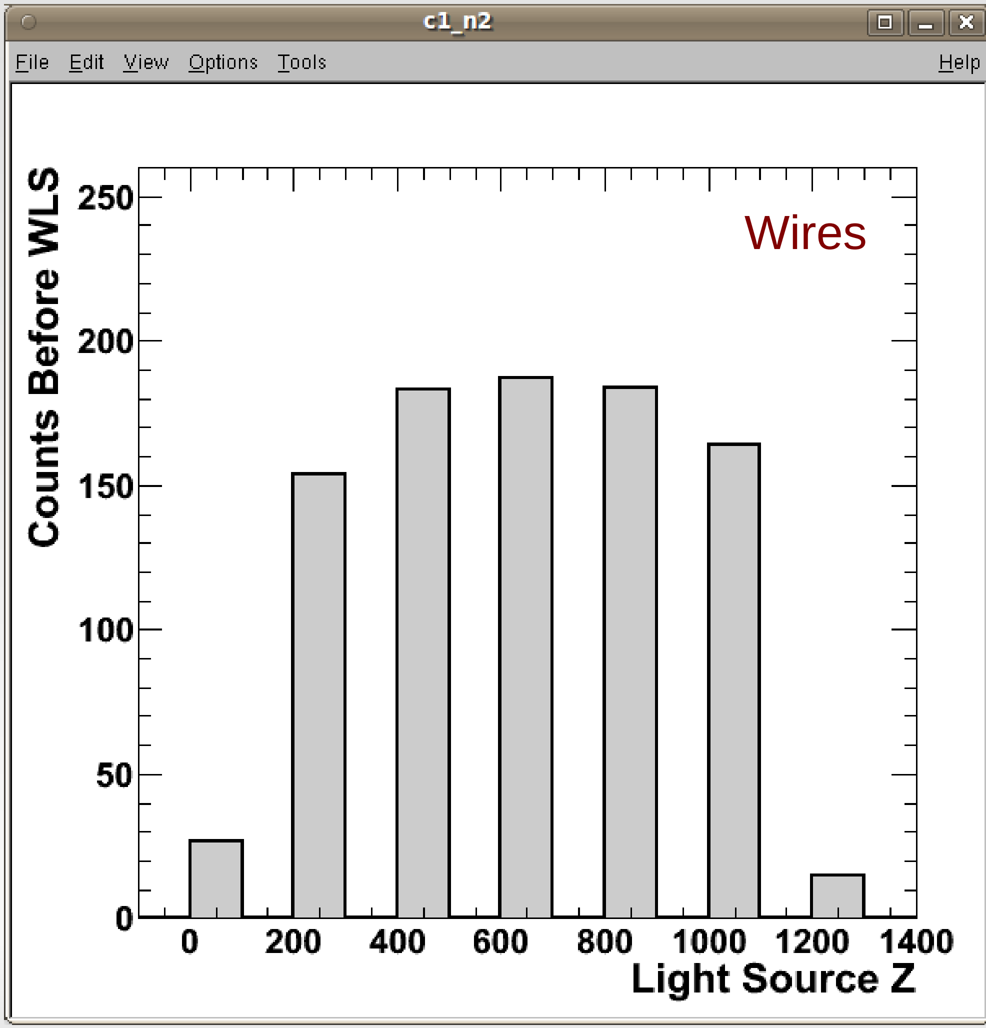
(Subject to geometry modifications)

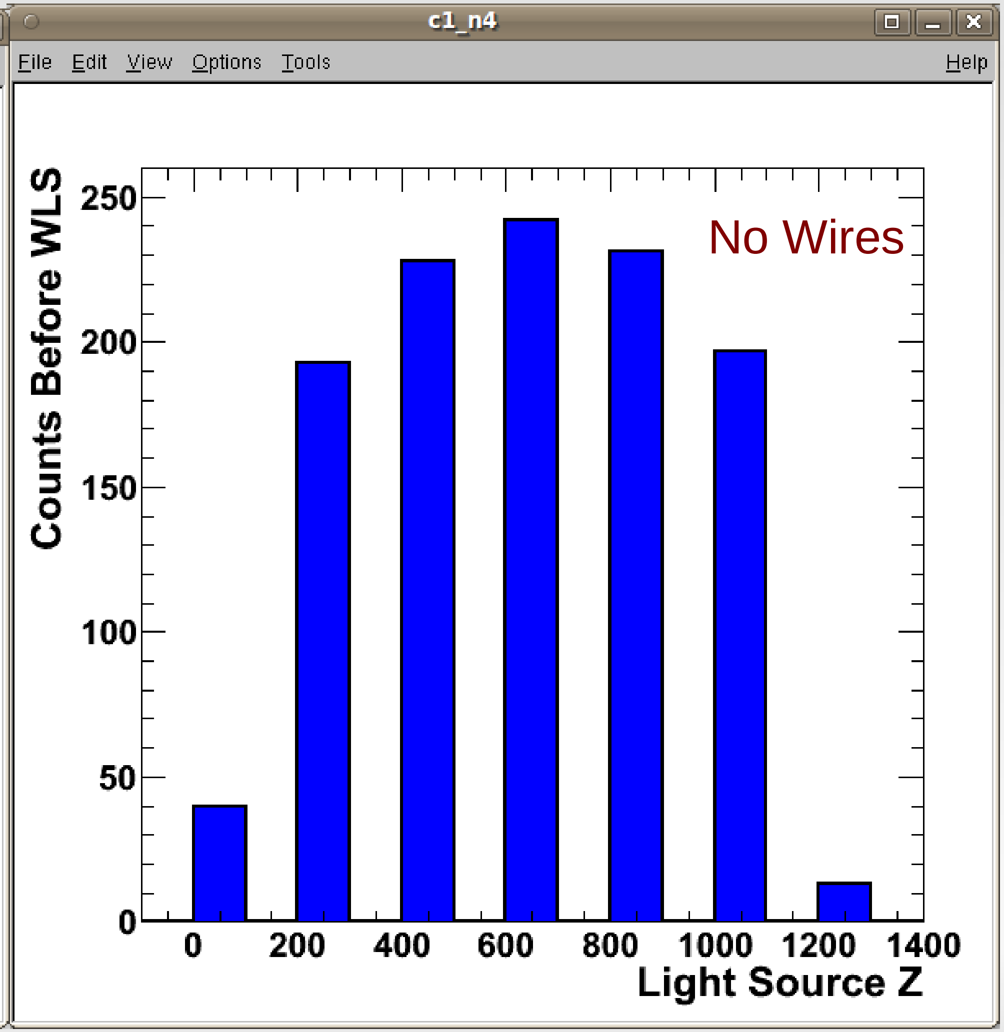
Preliminary – Point Source Test



Preliminary – Effect of Wires

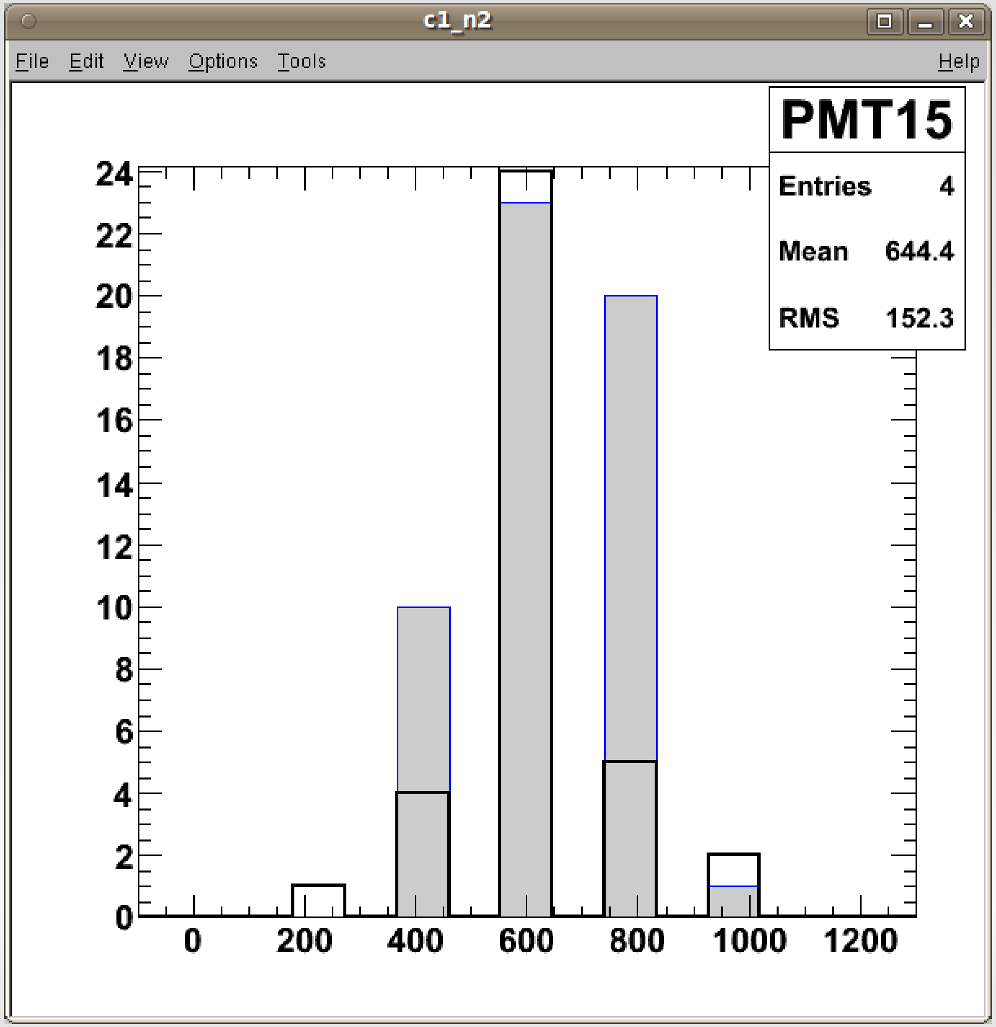
- Wires block ~20% of the light. Note the flattening...

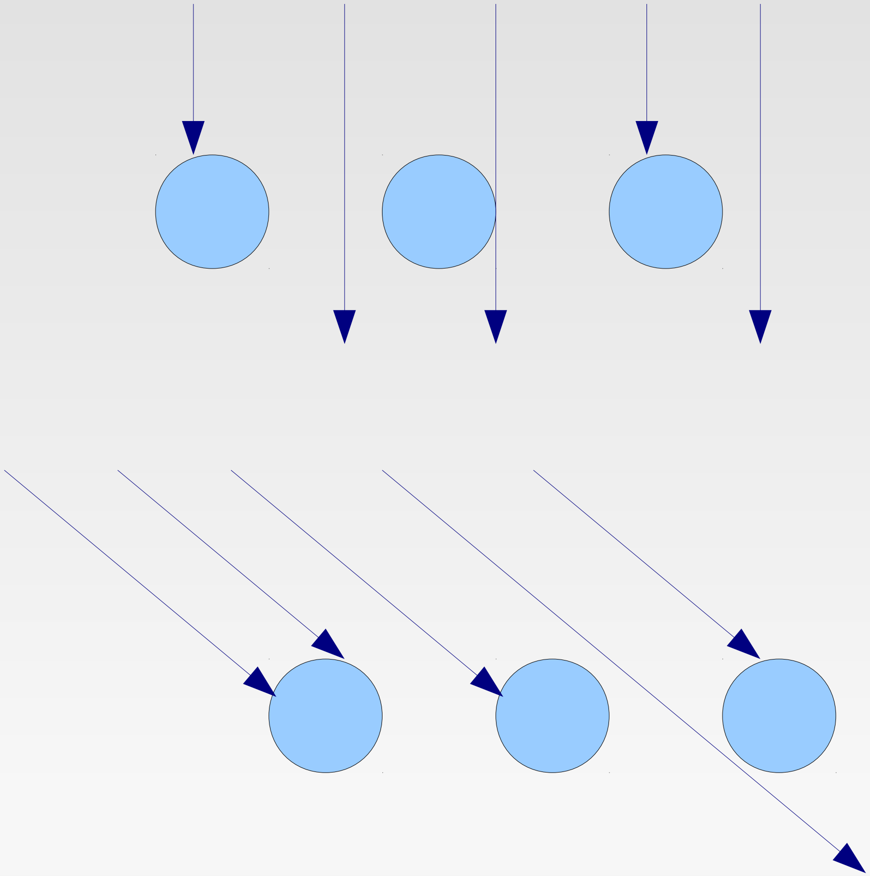




Preliminary – Effect of Wires

- Considering only one central PMT – note that the large angle light is more strongly blocked. Explains the flattening on the previous slide.

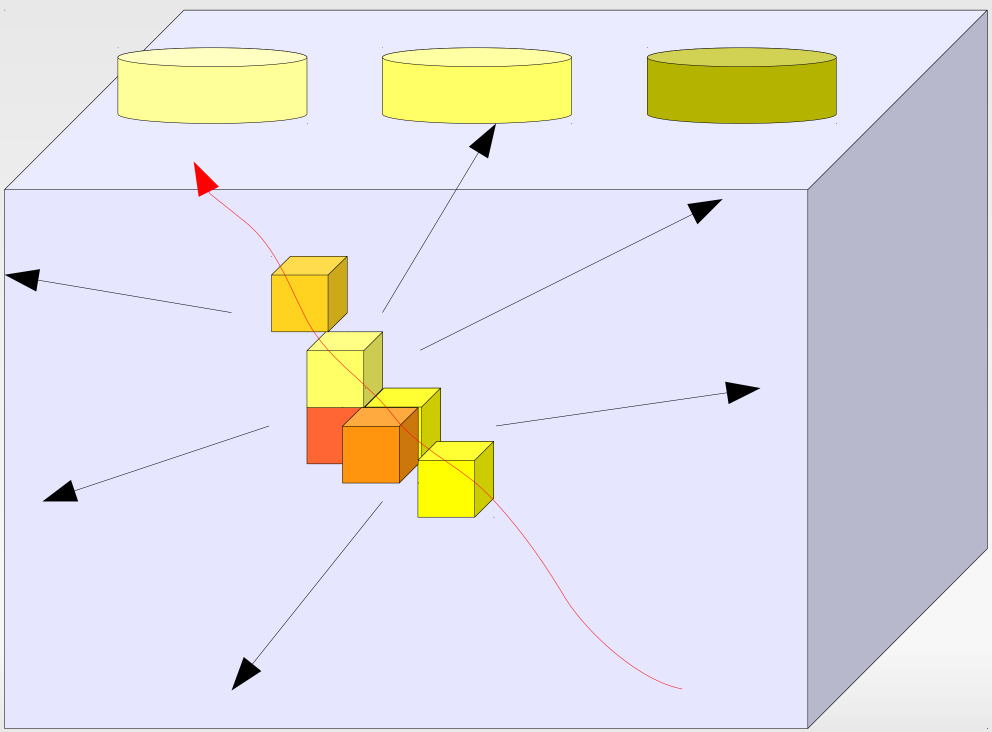




5 – Fast Simulation

Fast Simulations and Photon Library Sampling

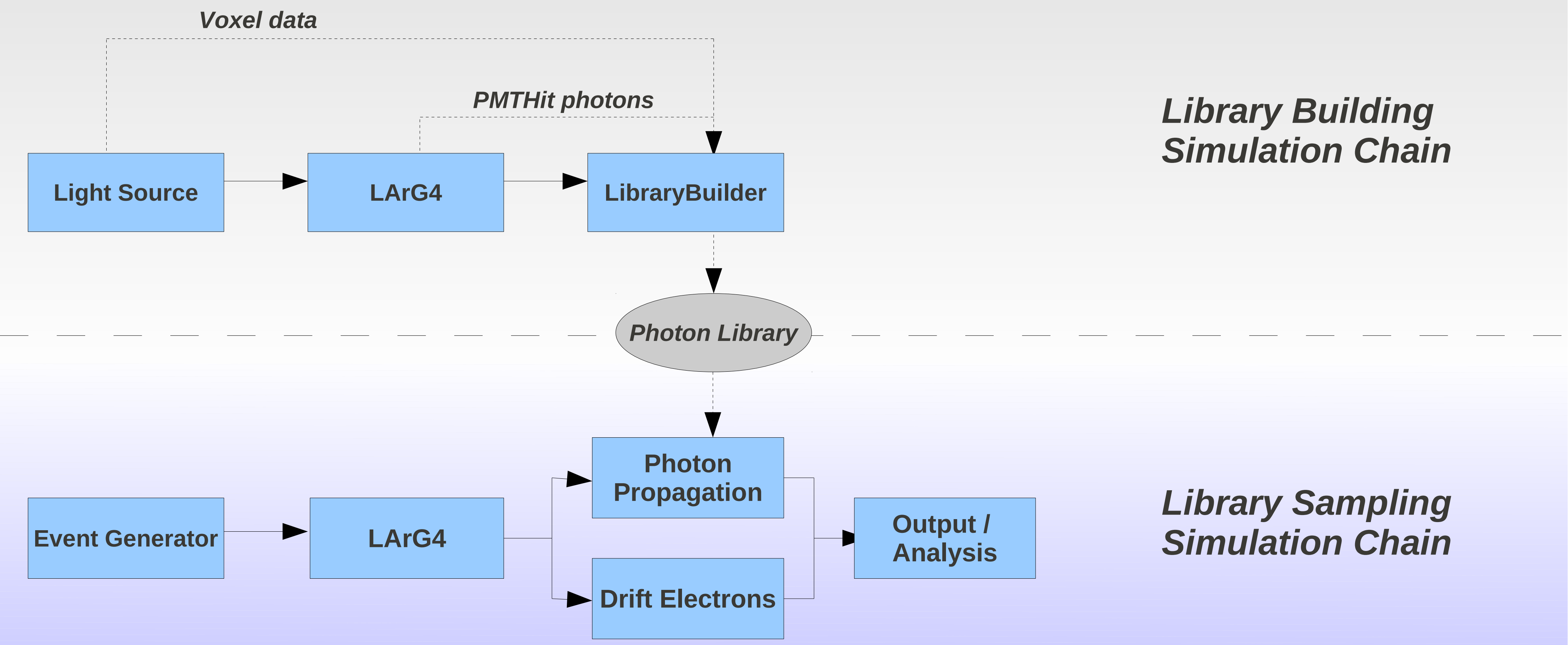
- GEANT4 simulation of 100,000s of photons per event takes a very long time – not a feasible approach for long monte carlo runs
- Scintillation photons are produced isotropically and in large numbers so we can take a different approach and sample from a library of typical responses



How many photons from each ”voxel” will reach each PMT?

How will their angles of incidence and positions on the PMT face be distributed?

Voxelized PhotonLibrary Building And Sampling Chains

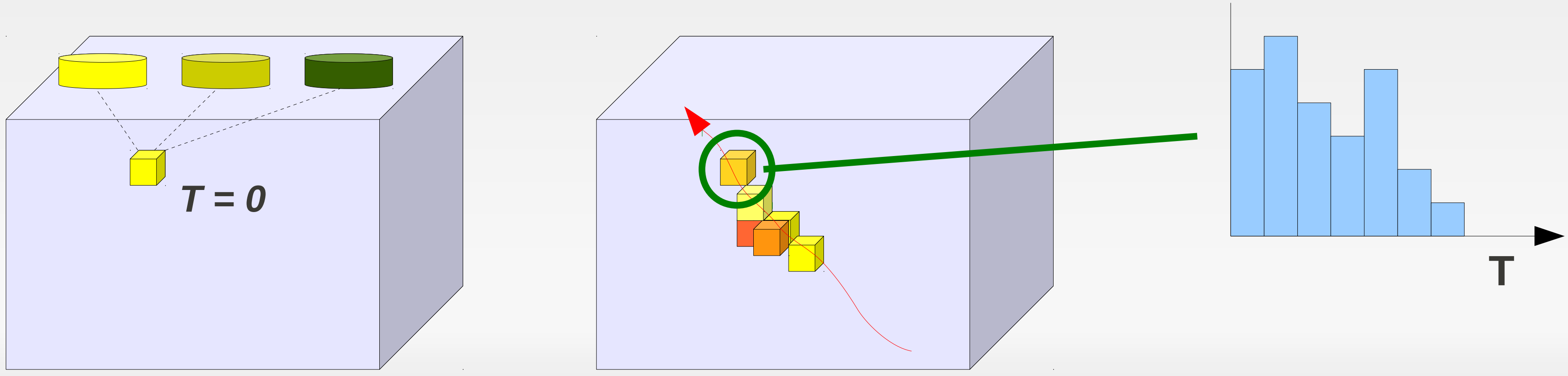


- Library is built using a light source with gaussian spectrum of **9.7 +/- 1 eV** in each voxel
- Later sampled by new module **PhotonPropagation**, which runs in parallel with DriftElectrons
- During the LarG4 step of the sampling chain, we do not step any photons, simply provide the **number produced in each voxel**

6 – To Be Implemented

TBI - Timing

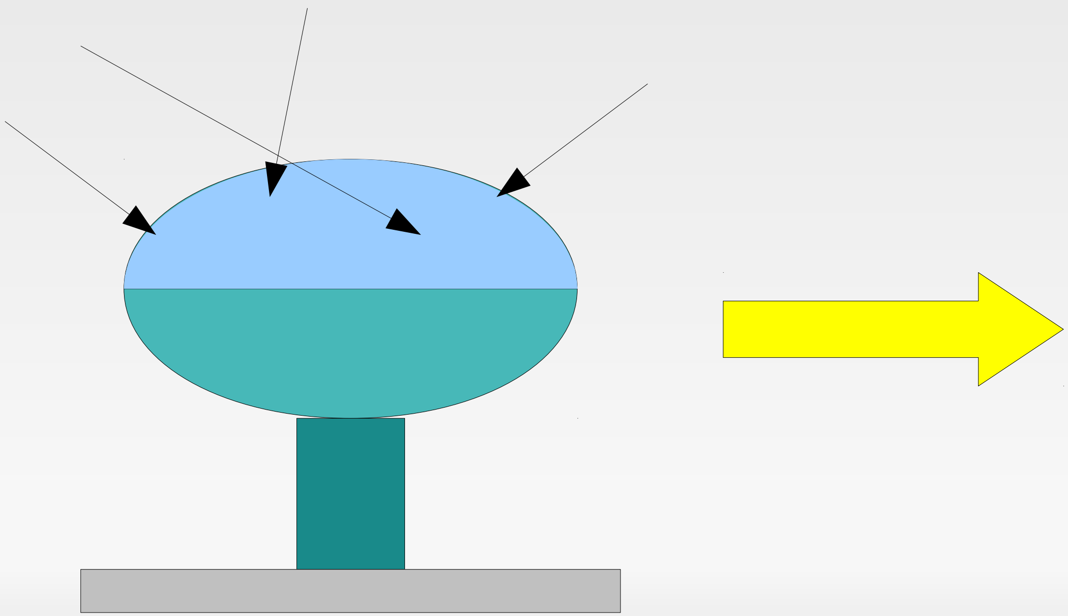
- One of the main tasks of the PMT's is triggering – here we require a coincidence with the beam window. Hence timing is important for trigger studies.
- Library entries are generated by photons at time **t = 0.**
- Accompanying **PMTHits store a time value** for each photon which reached the PMT
- But in the current voxelization scheme we lose the timing information for photons depositted.
- ***To be implemented*** : as well as reading # of photons per voxel, store a time profile for that voxel. Then time smear PMT hits sampled from library using this profile.

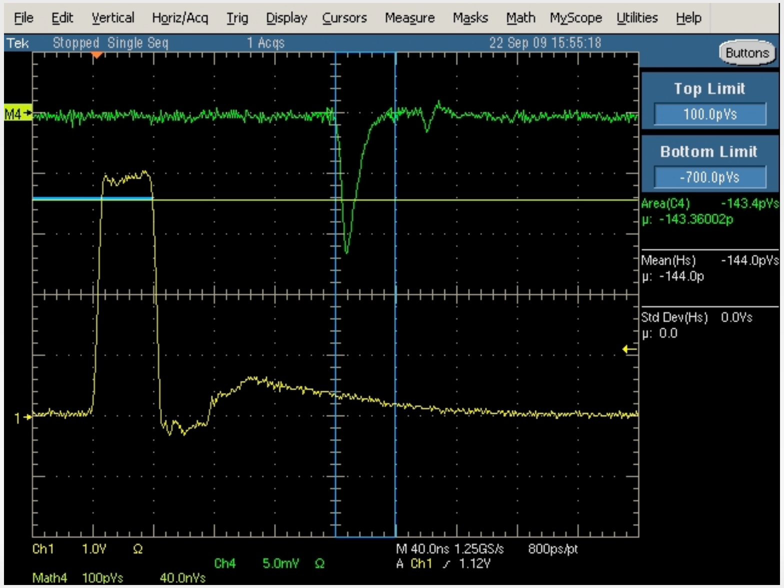


Library **LArG4**

TBI – Digitization / Pulse Shape Reconstruction

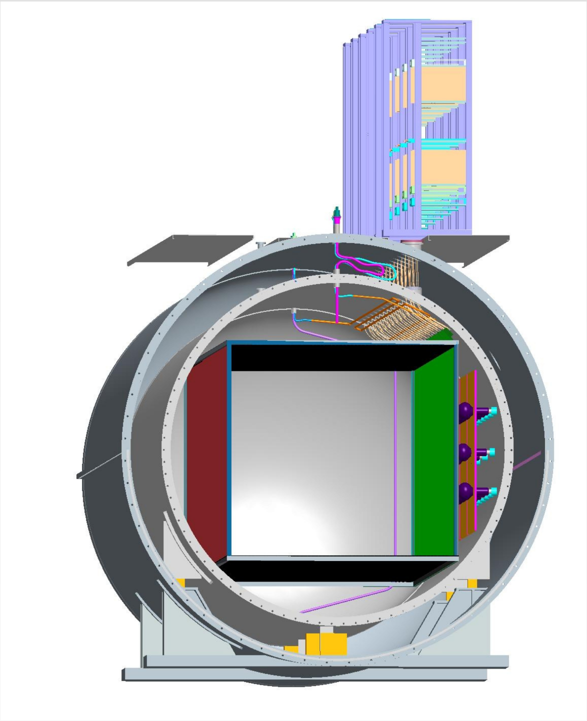
- Currently PMT hit data is a list of photons incident on the PMT surface
- We can use this to sample measured PMT efficiency curves and obtain an expectation of the number of photoelectrons per PMT
- We have not yet began to implement the digitization stage. Detailed PMT digitization simulations do exist (eg ***GLG4Sim***) and we may use these as a basis



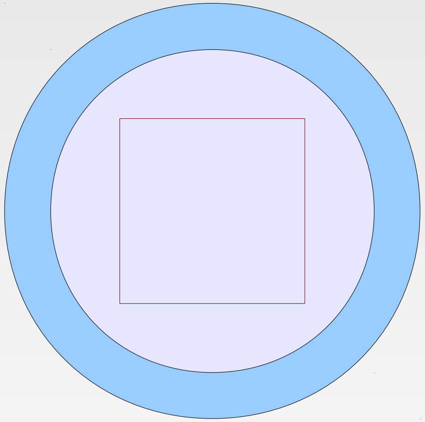


TBI – Geometry Rebuild

MicroBooNE



Not Microboone



- Detector dimensions have changed since decision to go into MiniBooNE hall, and this has not been accomodated in the simulation geometry
- Other aspects of the gdml description are also unsatisfactory and need work
- This is a problem for everybody doing MicroBooNE simulations and will be addressed imminently.

TBI - Detailed Studies in the Pipeline

- In its current state, the simulation is ready for the following studies, once computational resources become available and the detector geometry issue is addressed.

  - Trigger efficiency for scintillation light produced at each point in the detector volume
  - Coverage of each PMT as a function of position
  - Studies with PMT signals missing
  - Studies with modifications to the PMT geometry (40Rack, 30Rack-A, 30Rack-B etc)

- Further development is required for the following, but we hope to be there by December...

  - Determination of scintillation thresholds for triggering
  - Timing studies
  - Investigation of reconstruction applications
  - Parameterized optical sim as a component of the standard simulation chain

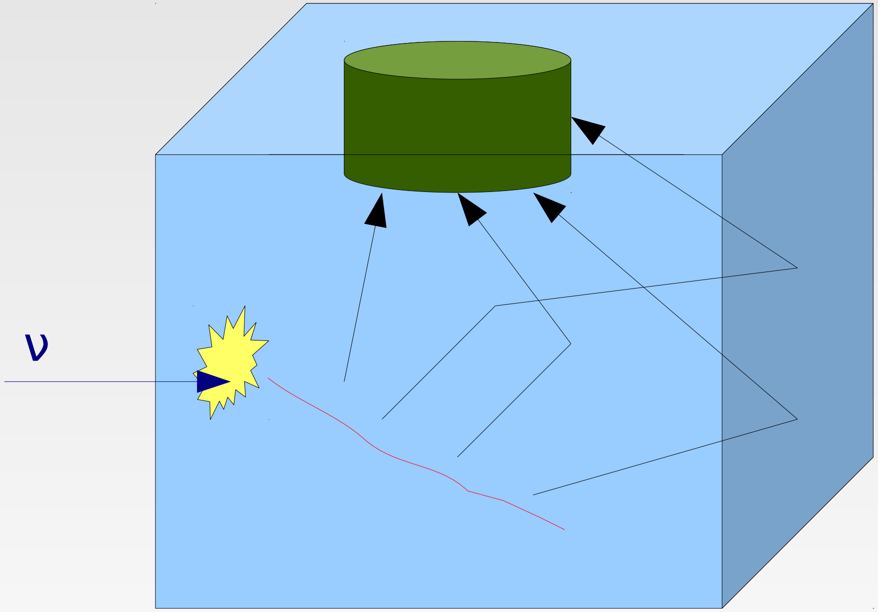
Summary

- A detailed optical simulation for scintillation and Cerenkov light in liquid argon has been developped within the LArSoft framework
- Optical system geometry definition scripts and a specific PMT geometry for the MicroBooNE detector have been implemented
- Preliminary studies using simulated light sources suggest ample PMT coverage for triggering at all detector locations except the corners of the TPC with significant redundancy
- Full studies will be performed when computing facilities become available
- A parameterized fast optical sim has been implemented and will eventually form part of the standard MicroBooNE simulation chain
- The optical simulation is in good shape and we hope to have extensive simulation results to show by December 2010.

Backup Slides

Photon Stepping

- Photons are produced via either scintillation or cerenkov production along the track of a charged particle in GEANT4.
- They are then stepped geometrically through the detector.
- Bulk absorptions and rayleigh scatters occur at random at the end of each step
- At an interface, a random specular or diffuse reflection, or absorption is applied according to the supplied reflectivity properties
- If a photon is incident upon a wavelength shifting volume, it is randomly absorbed according to a supplied absorption spectrum, and one or more photons are randomly emitted according to a supplied emission spectrum
- If a photon steps into a ”sensitive” volume, it is stopped and killed and a PMT hit is generated



Voxelized Library Sampling